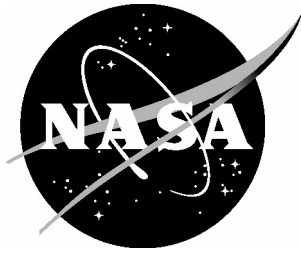


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Optically Based Flame Detection in the NASA Langley 8-ft High-Temperature Wind Tunnel

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May 2005

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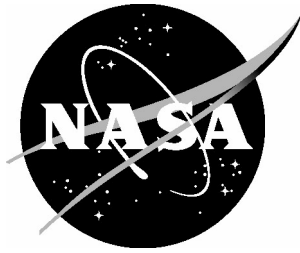
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ABSTRACT

Two optically based flame-detection systems have been developed for use in NASA Langley's 8-Foot High-Temperature Tunnel (8-ft HTT). These systems are used to detect the presence and stability of the main-burner and pilot-level flames during facility operation. System design considerations will be discussed, and a detailed description of the system components and circuit diagrams will be provided in the Appendices of this report. A more detailed description of the manufacturing process used in the fabrication of the fiber-optic probes is covered in NASA TM-2001-211233.

DEFINITIONS

8-ft HTT	NASA Langley Research Center's 8-ft High Temperature Tunnel (B1265)
OFD	Optical Flameout Detector
OPFD	Optical Pilot Flame Detector
PMT	Photomultiplier Tube
NO/NC	Normally Open/Normally Closed
T_r	% Transmittance
ND	Neutral Density #

INTRODUCTION

This paper documents the design, fabrication and integration of the various optically based flame-detection systems developed for use in the combustor of NASA Langley Research Center's 8-ft High-Temperature Wind Tunnel. The original optical system was designed to detect the presence of the combustor's main-burner flame during facility operations. Eventually a derivative of this system was developed to monitor the pilot-level flame, replacing a less reliable thermocouple-based sensing system. The technical specifications and other pertinent data for both systems are covered in this report. A more detailed description of the manufacturing process used to fabricate the optical probes is covered in a separate report, NASA TM-2001-211233 [1].

BACKGROUND

NASA Langley Research Center's 8-Foot High-Temperature Tunnel (8-ft. HTT) is a large-scale hypersonic facility that utilizes a large air/methane combustor which can be configured to generate test section free-stream flow velocities of Mach Numbers 4, 5, or 7. This facility uses an open-jet test section that can simulate atmospheric conditions from 18 to 38 kilometers (60,000 to 125,000 feet) in altitude. [2] (Figure 1)

Concerns over an unplanned combustor flameout and re-ignition led to the development of several new flame-detection technologies with response times of less than 100 milliseconds. Results of these studies yielded two new flameout detection techniques – an acoustic-based and an optical-based system. The acoustic-based system detects the presence of selected acoustic resonances within the

combustor that are indicative of stable combustion. The optical-based system infers flame activity by monitoring combustor light levels over a select wavelength range.[3]

This paper discusses the development of the optically based flameout detector (OFD) as a viable technique for monitoring the presence of the combustor's main-burner flame, and its adaptation as an effective optical pilot-level flame detector (OPFD).

THEORY OF OPERATION

Both the OFD and OPFD systems were designed to respond to gross changes in combustor light intensity over a specific wavelength range. For redundancy, the OFD system employs two independent electro-optical detectors and triggering circuits while the OPFD utilizes just a single detector and trigger. Both optical systems have a less than 10-millisecond response time to a step function change in light intensity. (Figure 2)

Both systems can be configured for operation over a broad wavelength range with a variety of optical detectors. Currently, both optical systems utilize a photomultiplier tube (PMT) detector to monitor ultraviolet/visible light intensity levels from approximately 200 to 600 nanometers. Use of the photomultiplier tube as the basis for these optical systems is what gives them their exceptional sensitivity and fast response time to changing light-intensity levels within the combustion chamber.

Light energy from the combustion process is transmitted to the PMT optical detectors via fiber-optic probes. The outputs of the photomultiplier tubes are electronically buffered and used to activate logic circuitry that determines if a flame on/off condition exists within the combustor. Characterizing the detector's response to the various combustor light-intensity levels associated with different flames (pilot, boost, and main burner) was arrived at through experimentation.

In order to generate a main-flame "on" indication from the detection circuitry, the detector output voltage must exceed a preset minimum value corresponding to the light intensity associated with a low-intensity boost

flame. Once this voltage level is reached, a FLAME ON condition is signaled to the facility control system. Conversely, if the detector outputs drop beneath a minimum value, then a FLAME OFF condition is realized. A FLAME OFF signal from the detection system is used to initiate a rapid shutdown of the main fuel supply.

The major components of the flame detection circuitry are a non-inverting amplifier, a voltage comparator, and two relays — one normally open (NO), and one normally closed (NC). The amplifier conditions the detector output for the fixed-voltage comparator. Variation of the amplifier gain changes the minimum detector output voltage required to generate a state-change in the fixed voltage level comparator. A 2:1 comparator turn ON/OFF voltage ratio is designed into the comparator circuitry to guard against false triggers from reflections within the combustor. When the comparator undergoes a change in state, a corresponding state change will also occur in the NO/NC relay. The relay combination is the flameout detection system's trigger that is monitored directly by the facility's process-control system. Careful design of the comparator/relay combination insures that a "FLAME OFF" signal is generated in the event of a power/component failure.

The OPFD and OFD systems are configured to respond to different combustor light-intensity levels during facility operation. The OPFD must be able to respond to lower light-intensity levels than the OFD. The OPFD is used to detect the *ignition* of the pilot flame, a low-intensity flame used to ignite successively larger flames within the combustor. In comparison, the OFD is designed to monitor against a sudden *extinction* of the main-burner flame, the largest flame source in the combustor.

To further improve the response time of the OFD system to a sudden flameout condition, a #2 neutral-density optical filter was selected to limit photon flux on the detector. This allows the detector's output voltage to fall below the set point at a higher combustor light intensity level. Use of this filter corresponds to a 99% reduction in the photon flux on the detector.

$$T_r = 10^{-ND}$$

FACILITY SYSTEM INTEGRATION

The OPFD and OFD systems are external to the combustion chamber within a pressurized (air @ 30 KPa - 5 psi) enclosure. They are optically coupled to the light energy radiated from air/methane combustion with fiber-optic probes. (Figure 3) The optical probes are cut to length for each system and are designed specifically for operation in the combustor's high-pressure (28 MPa-4000 psi) oxidizing environment. The optical probes penetrate the combustor shell through high-pressure fittings and are routed within the combustor to optimal viewing locations. The fiber-optic probes do not possess focusing optics, and are able to see events occurring within a 14-degree conical field-of-view. A more detailed description of the fiber-optic probes, including their design and manufacture, can be found in reference 1.

OFD System Considerations

A pair of optical probes for the OFD system are rigidly mounted to the fuel spray bar behind the main flame. They are co-aimed to look through the center airfoils of the spray bar and transversely across the flow of oxidizing gases at a region of the combustor wall roughly 38 centimeters (15 inches) in front of the fuel spray bar. (Figure 4)

Selection of this optical path permits the detection system to respond faster to a potential flameout if the flame front leaves the fibers' field-of-view.

OPFD System Considerations

A single optical probe is used by the OPFD system. This probe is routed along the methane fuel injector to the igniter assembly. The end of the probe is rigidly mounted to the igniter assembly under the pilot burner. (Figure 5) The probe should be aimed to view the area in front of this assembly where the oxidation of the fuel is predicted to occur.

OFD SYSTEM PERFORMANCE & RELIABILITY

The OFD system was initially developed for use in the 8-ft. HTT in April 1992, and it was formally incorporated into the facility's process control network as a configuration-controlled device in May 1993. The OFD system has been in continuous operational use since this time and

is considered a critical safety element in the tunnel's process control system. In the event that a sudden combustor flameout is detected, the OFD system has the ability to initiate a rapid shutdown of the facility's main fuel system.

OPFD SYSTEM PERFORMANCE & RELIABILITY

The OPFD system replaced a less reliable thermocouple-based flame detector and has been in continuous service since 2001. No failures have been recorded to date. The OPFD system is also considered a configuration-controlled device in this facility and is 100% interchangeable with the related OFD system on the component and calibration level. Individual components and/or calibrated circuit boards can be swapped between two OPFD/OFD systems with no loss in system performance. Note that the OPFD system does not use an optical neutral density filter since it must detect the activity of the pilot flame's low-light intensity flame.

CONCLUSIONS

The OFD & OPFD systems are exceptionally fast-responding devices. Laboratory calibration and testing of the system's response time were made using a step change in light flux. These tests indicated the measured response time of the system, from detection to relay closure, was under 10 milliseconds.

REFERENCES

1. Borg, S.; Harper, S.: *A Fiber-Optic Probe Design for Combustion Chamber Flame Detection Applications*, NASA TM-2001-211233; October 2001.
2. Hodge, J.; Harvin, S.: *Test Capabilities & Recent Experiences in the NASA Langley 8-ft High-Temperature Tunnel*, 21st AIAA Advanced Measurement Technology and Ground Testing Conference, Denver, CO; June 19-22, 2000.
3. Puster, R.; Brown, R.; Borg, S.: *Fuel Injectors, Flameout Detectors and Oxygen-Monitoring Systems for the Langley 8-ft High-Temperature Tunnel*, 78th Meeting of the Supersonic Tunnel Association, Melville, NY; October 19-20, 1992.

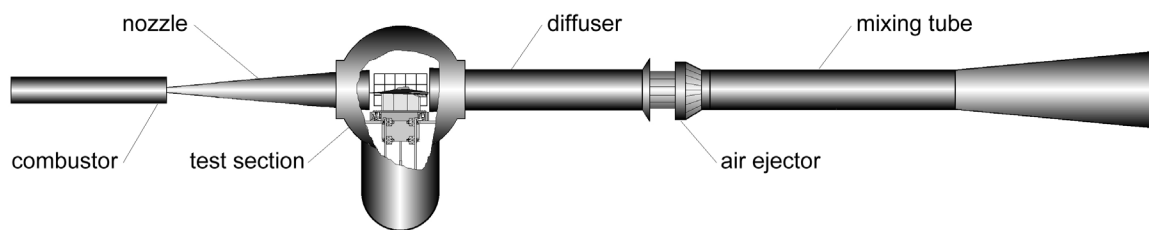
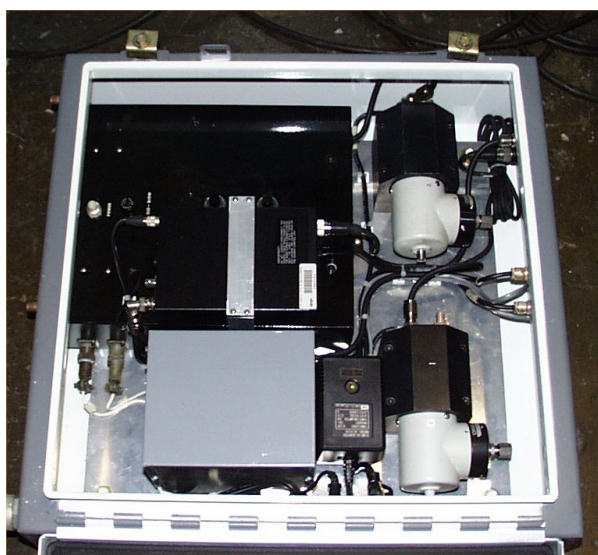


Diagram of the NASA Langley 8-ft High-Temperature Tunnel.

FIGURE 1



2a. Optical Flameout Detector Enclosure



2b. Optical Pilot Flame Detector Enclosure

FIGURE 2



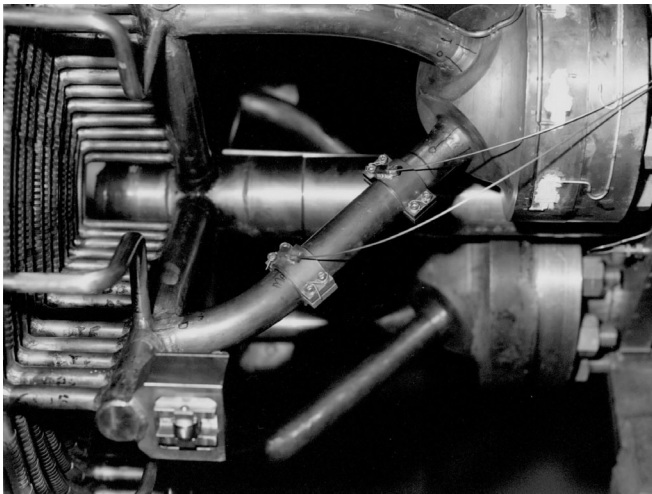
3a. Optical Flame Detector



3b. Optical Pilot Flame Detector

Optical system enclosures shown mounted on combustor closure plug cart.

FIGURE 3



4a. OFD probe orientation on the concentric ring fuel injector



4b. OFD probe mounted to the airfoil fuel injector.

FIGURE 4

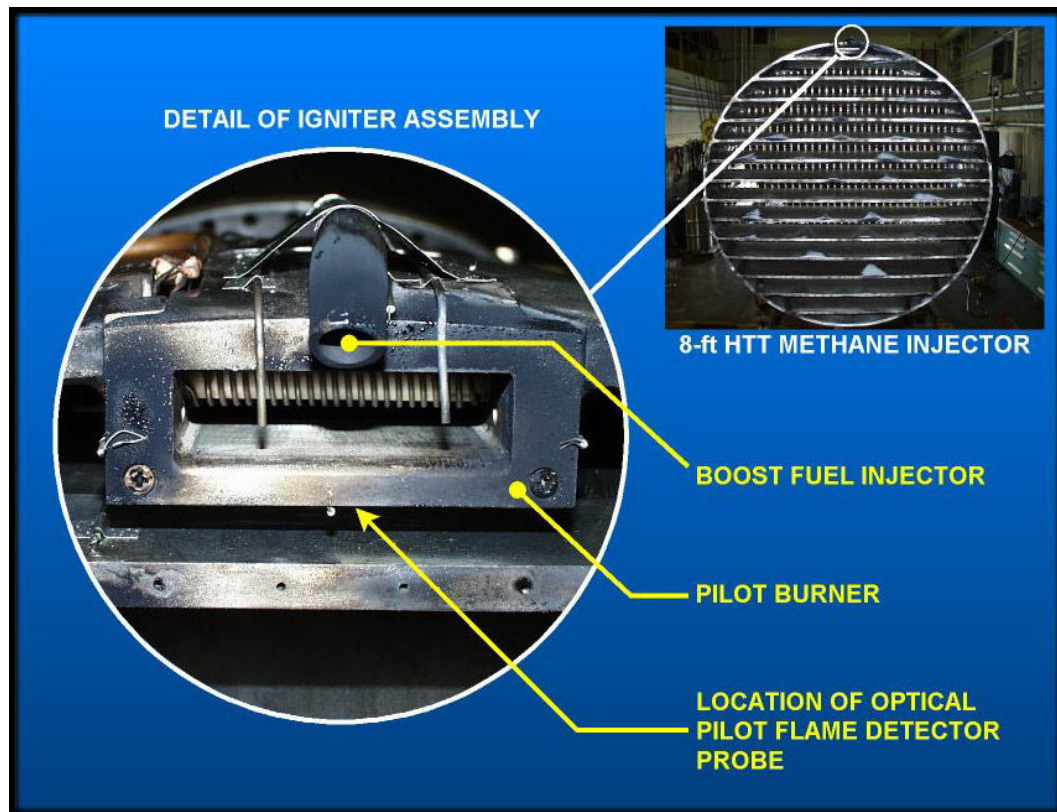


Diagram of the OPFD probe orientation on the igniter assembly
FIGURE 5

APPENDIX A

OFD & OPFD SYSTEMS SIGNAL PATH

Refer to Wyle drawing C20265100, the level detector PCB consists of five circuit sections. The signal-conditioning path is as follows;

1. A Transimpedance Amplifier (TIA) U1 (ADOP27CH), PMT current to voltage converting amplifier.
2. An adjustable 1 to 11 voltage gain non-inverting amplifier U2 (ADOP27CH). At this point the signal takes two separate paths (3a & 3b).
- 3a. U4, gain of 1 buffer amplifier, (ADOP27). This signal is output to P1 pin 14, and may be utilized for viewing or recording the flame output signal.
- 3b. Voltage comparator U3 (LM311) with a fixed one volt FLAME OUT threshold and an adjustable FLAME ON threshold.
4. An adjustable FLAME ON time delay stage, Q1 (IRFD9120).
5. Two dry reed relays, one normally open and one normally closed, which provide the closure signal to the process control system. The description is typical of channel 1 and 2. The comparator and the normally open and normally closed relay combination are designed to insure that after power up or in the event of unit power failure a FLAME OUT indication will occur.

Transimpedance Amplifier (TIA) U1

This input section may be configured for either a current or voltage output type sensor, by inserting the selected component carrier in socket MOD 1. The PMT utilizes the current input component carrier and op-amp U1 (ADOP27CH) with a fixed gain of 5×10^4 or 50-millivolts/microampere. The amplifier output voltage is a direct multiple of sensor output current times the amplifier feedback resistor (50-k Ω). The voltage input component carrier bypasses U1 and allows a voltage output type sensor to drive U2 directly.

Amplifier U2

U2 is an adjustable 1-11 voltage gain amplifier. U2 conditions the TIA output signal for the voltage level comparator U3 and buffer amplifier U4. Circuit potentiometer R5 labeled GAIN is provided to set amplifier gain. The gain control should be set to produce a 12-volt average output, during normal combustion, at J1 pin 14.

The optimum gain setting should be re-evaluated in the event the fiber optics are realigned or replaced. The amplifier's input resistor and capacitor network (R3 C10) is a low pass filter with a 3db down roll off of 132-Hz. This filter reduces the level detectors' susceptibility to extraneous noise spikes

Voltage Comparator U3

Initially after power up and or during a FLAME OUT condition the output of comparator U3 pin 7 (LM311) is low. This condition enables the comparator input voltage divider comprised of R8 (5.1-k Ω), R11 (270 ohm) and R12 (5-k Ω trim pot). This adjustable divider determines the FLAME ON voltage level. Once the required level has been achieved to produce 1-volt at the input of U3 pin 2, U3 pin 7 will transition high, indicating FLAME ON. The fixed 1-volt trip threshold is determined by voltage divider R6 (27-k Ω), R7 (2-k Ω). During FLAME ON U3 pin 7 is high, this condition disables the voltage divider comprised of R8, R11 and R12. Consequently the input signal level required to produce a FLAME OUT indication becomes 1 volt. The circuit potentiometer R5, labeled FLAME ON, can be set for a FLAME ON threshold level of 2 to 8 volts.

FLAME ON Delay

The discrete component circuit section comprised of CR1, C11, R13 and Q1 provide an adjustable one-way time delay. The previous stage (U3) has an open-collector output, which in conjunction with CR1 allows the voltage on the gate of Q1 to transition high based on the adjustable time constant of C11 and R13. This section delays FLAME ON only and has no delay impact on FLAME OUT. R13, labeled DELAY, may be set for a time delay of 0.065 to 1.3 seconds.

APPENDIX B

OFD & OPFD ADJUSTMENT PROCEDURES

The electro-optic signal representing combustion light flux contains static and dynamic signal components. The flame flicker produces the dynamic signal component and is about 30 percent of overall. The design and adjustment of this circuitry is intended to preclude the dynamic signal transitions as the FLAME ON or FLAME OUT component. New adjustment settings can be recorded on a calibration table found at the end of this section.

Test Equipment Required

Function Generator: Hewlett-Packard Model 3312A or equivalent
Multimeter: Keithley Model 192 or equivalent
Oscilloscope: Hitachi Model VC-6025 or equivalent
Signal Generator: Keithley Calibrator Model 263 or equivalent

Comparator FLAME ON Level Adjust

1. Insert the voltage input configuration component carrier.
2. Disconnect the PMT signal output cable from the PMT housing. This cable then becomes the test signal input.
3. Adjust R5 fully clockwise, gain of 1.
4. Adjust R12 fully clockwise, maximum FLAME ON voltage. Adjust R13 fully clockwise, minimum time delay.
5. Input the desired voltage chosen for the flame on level. Example: Input a 2-volt DC signal and measure the signal at U2 pin 6 to insure the gain of U2 is actually 1.
6. Monitor U3 pin 7 and verify that the output is low (<0.6-volts). This signal may be found at the junctions of CR1 and CR6. Slowly adjust R12 clockwise until U3 pin 7 toggles high, indicating FLAME ON.
7. Slowly decrease the input test voltage to <1-volt, while monitoring U3 pin 7 and verify that the output toggles low, indicating FLAME OFF. Slowly increase the input test voltage and re-verify that U3 pin 7 toggles high as the test signal transitions through 2-volts.
8. Reconnect the PMT signal output cable to the PMT housing connector.

FLAME ON Delay Adjust

1. Insert the voltage input configuration component carrier.
2. Disconnect the PMT signal output cable from the PMT housing. This cable then becomes the test signal input.
3. Input a 10-volt peak, 5-Hz, square wave.
4. Set the oscilloscope in dual channel mode, and input the test signal into channel 1 also. Trigger the oscilloscope from channel 1, with a positive slope.
5. Monitor the junction between Q2 and R9 and adjust R13 for the required transition delay after the positive rising edge of the test signal.
6. Reconnect the PMT signal output cable to the PMT housing connector.

Amplifier Gain Adjust

A gain of 3 is the initial setting.

1. Insert the SPD configuration component carrier module.
2. Disconnect the PMT signal output cable from the PMT housing. This cable then becomes the test signal input.
3. Input a 1-volt DC signal.
4. Monitor the signal at U2 pin 6 and adjust RS for a 3-volt indication.
5. Reconnect the PMT signal output cable to the PMT housing connector.

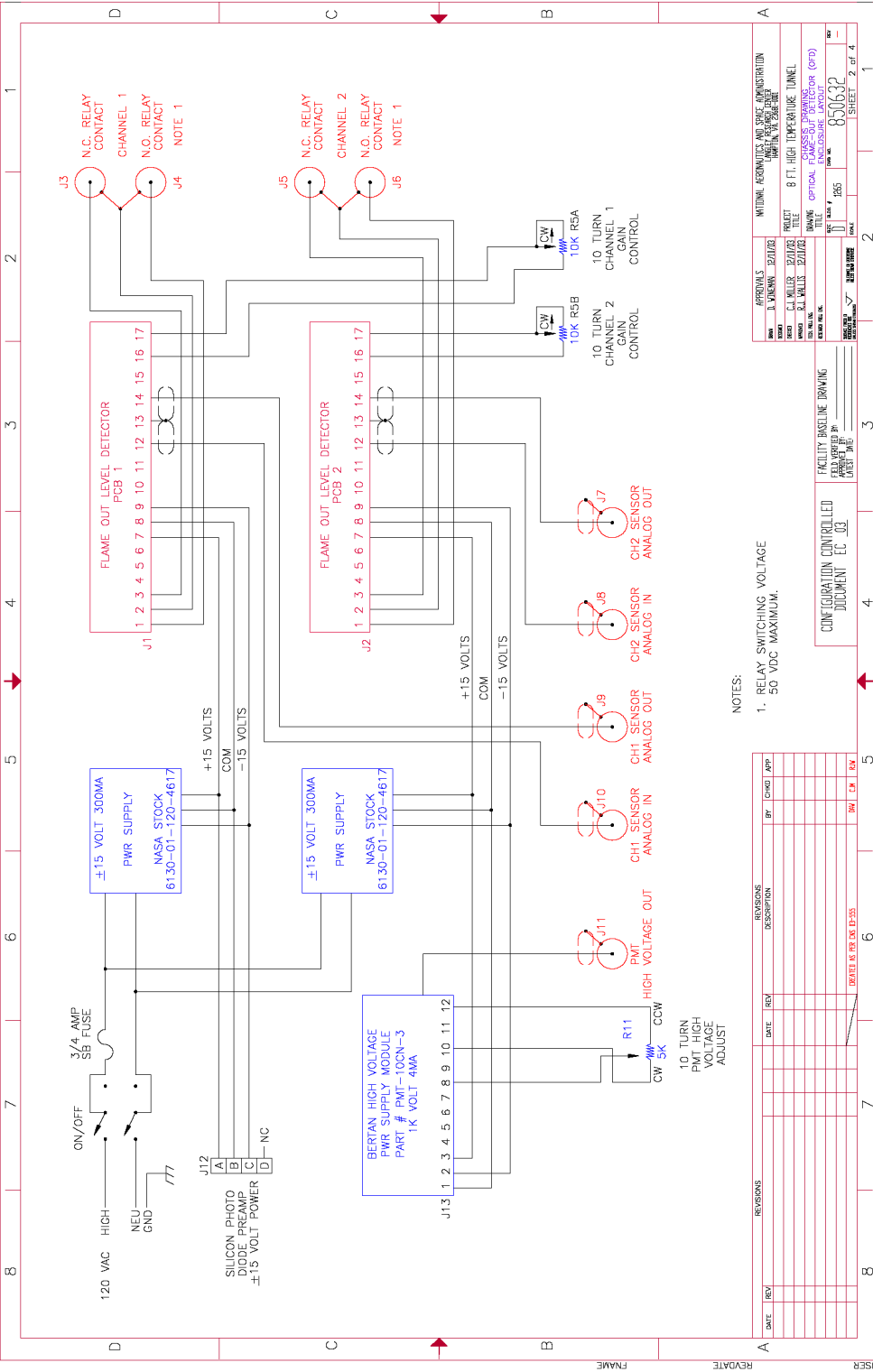
APPENDIX B
TABLE OF CALIBRATION SETTINGS

U2 GAIN SETTING							
FLAME ON VOLTAGE							
DELAY (seconds)							
DATE							

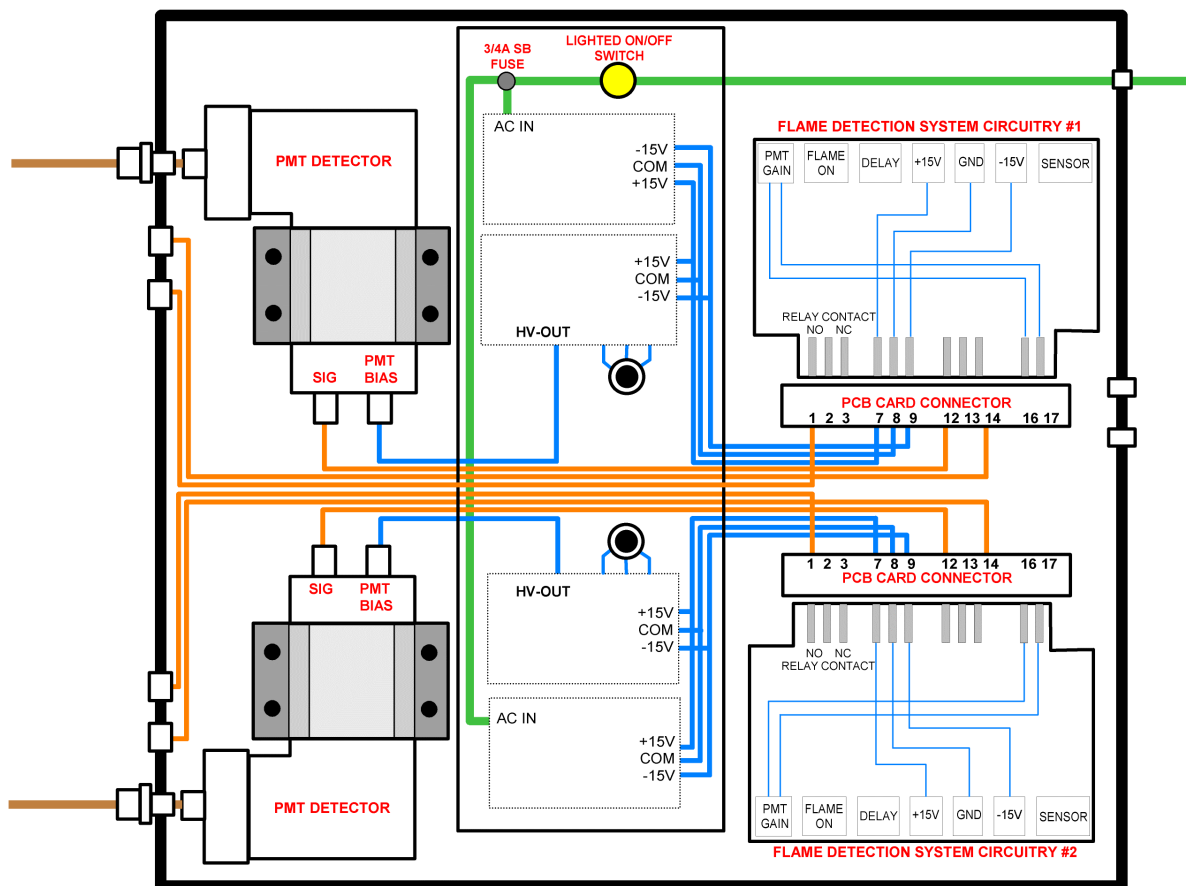
Circuit diagram for OFD & OPFD systems.



APPENDIX C
DRAWINGS, SCHEMATICS AND OTHER DOCUMENTATION

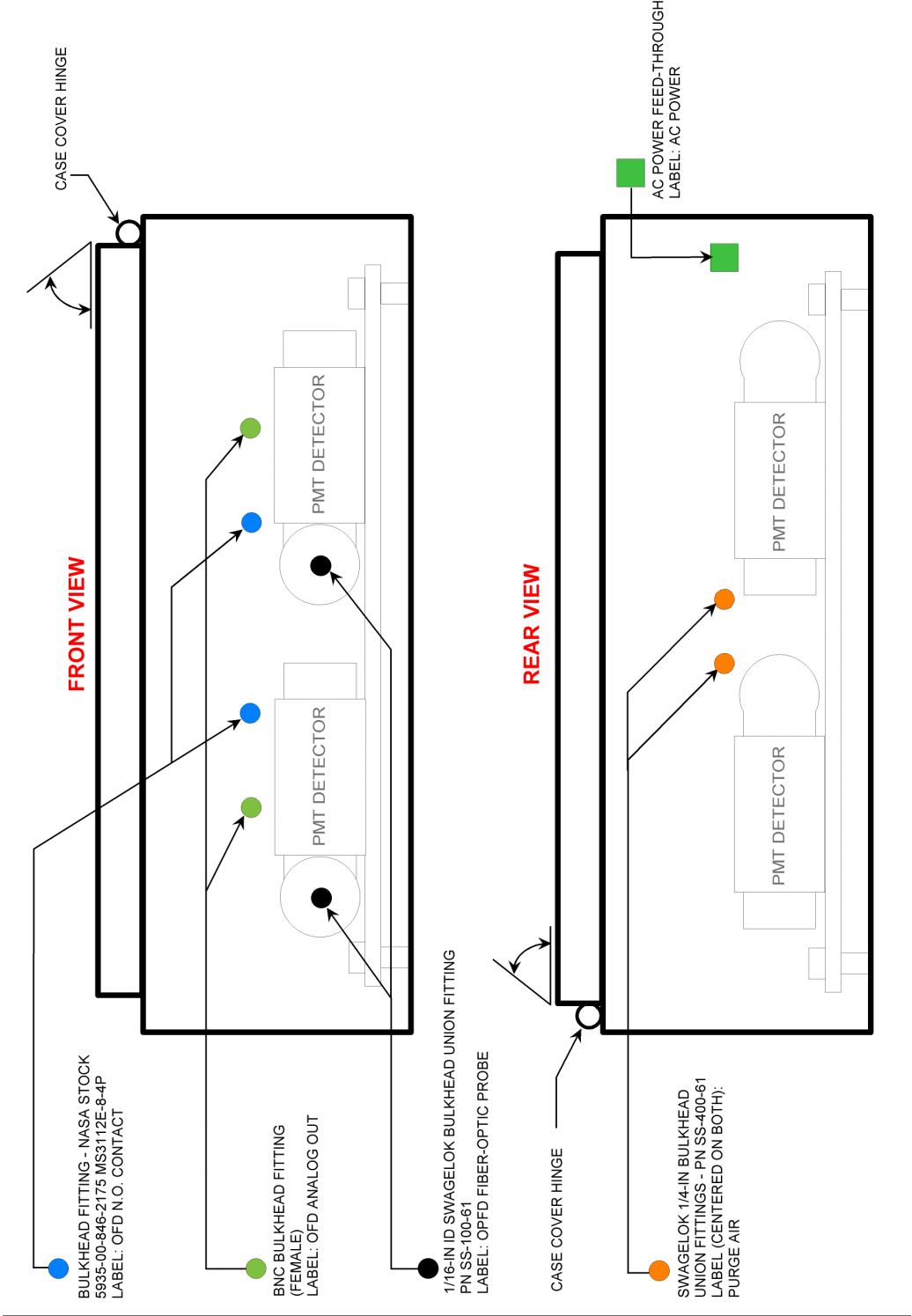


APPENDIX C **DRAWINGS, SCHEMATICS AND OTHER DOCUMENTATION**



OFD chassis component sketch

APPENDIX C
DRAWINGS, SCHEMATICS AND OTHER DOCUMENTATION



OFD chassis labeling & external connections

DRAWINGS, SCHEMATICS AND OTHER DOCUMENTATION

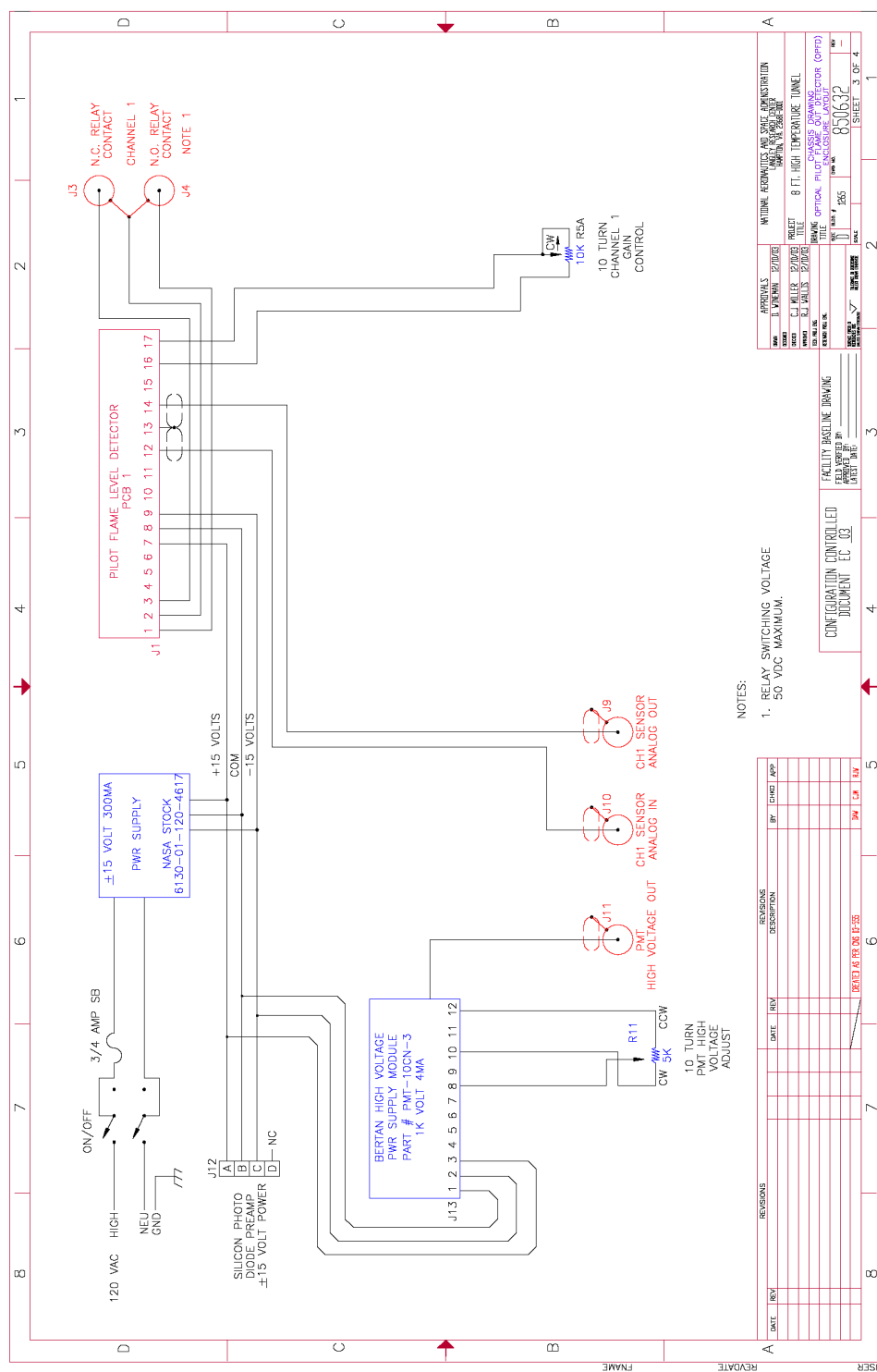
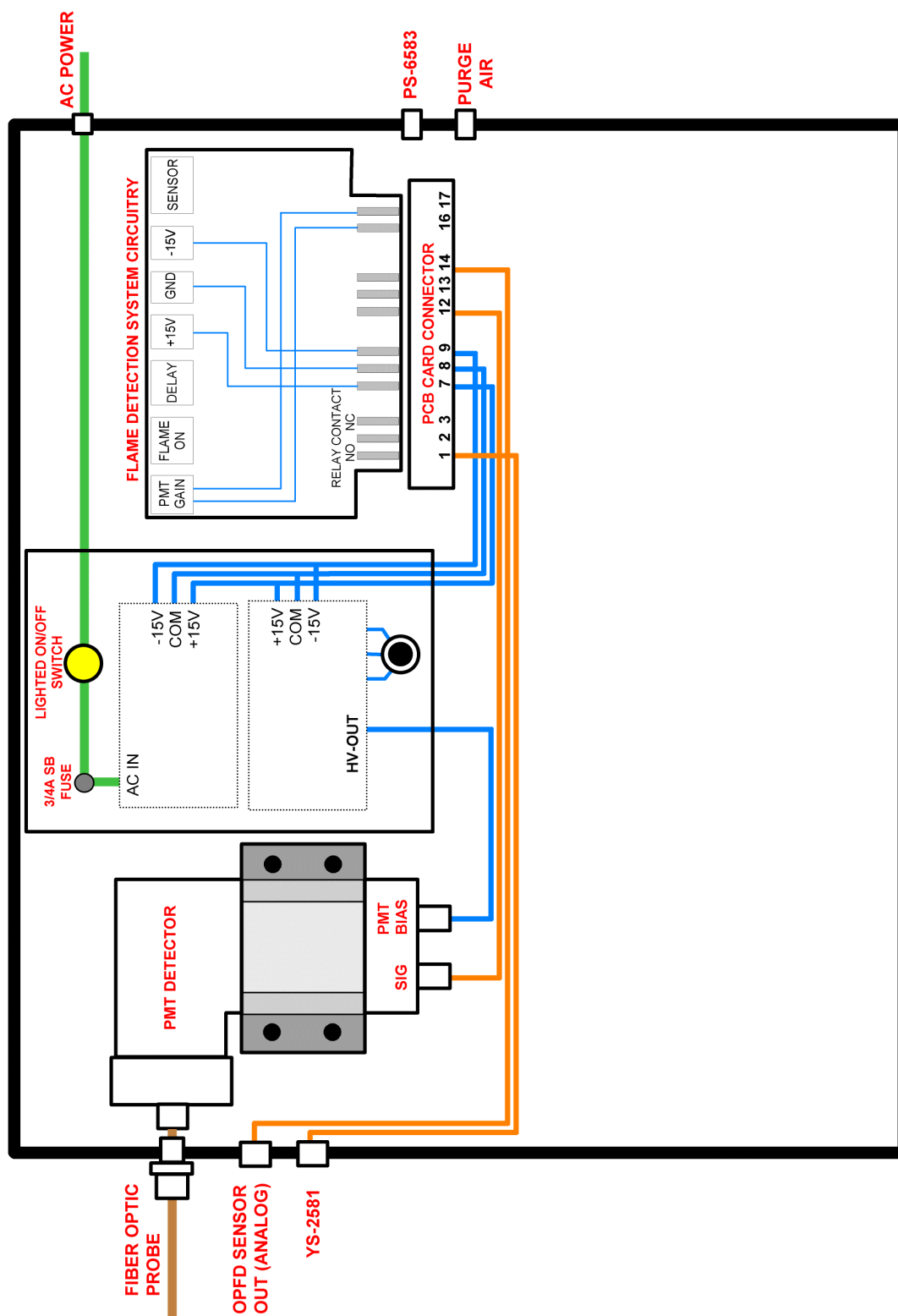


Diagram for OPFD chassis layout

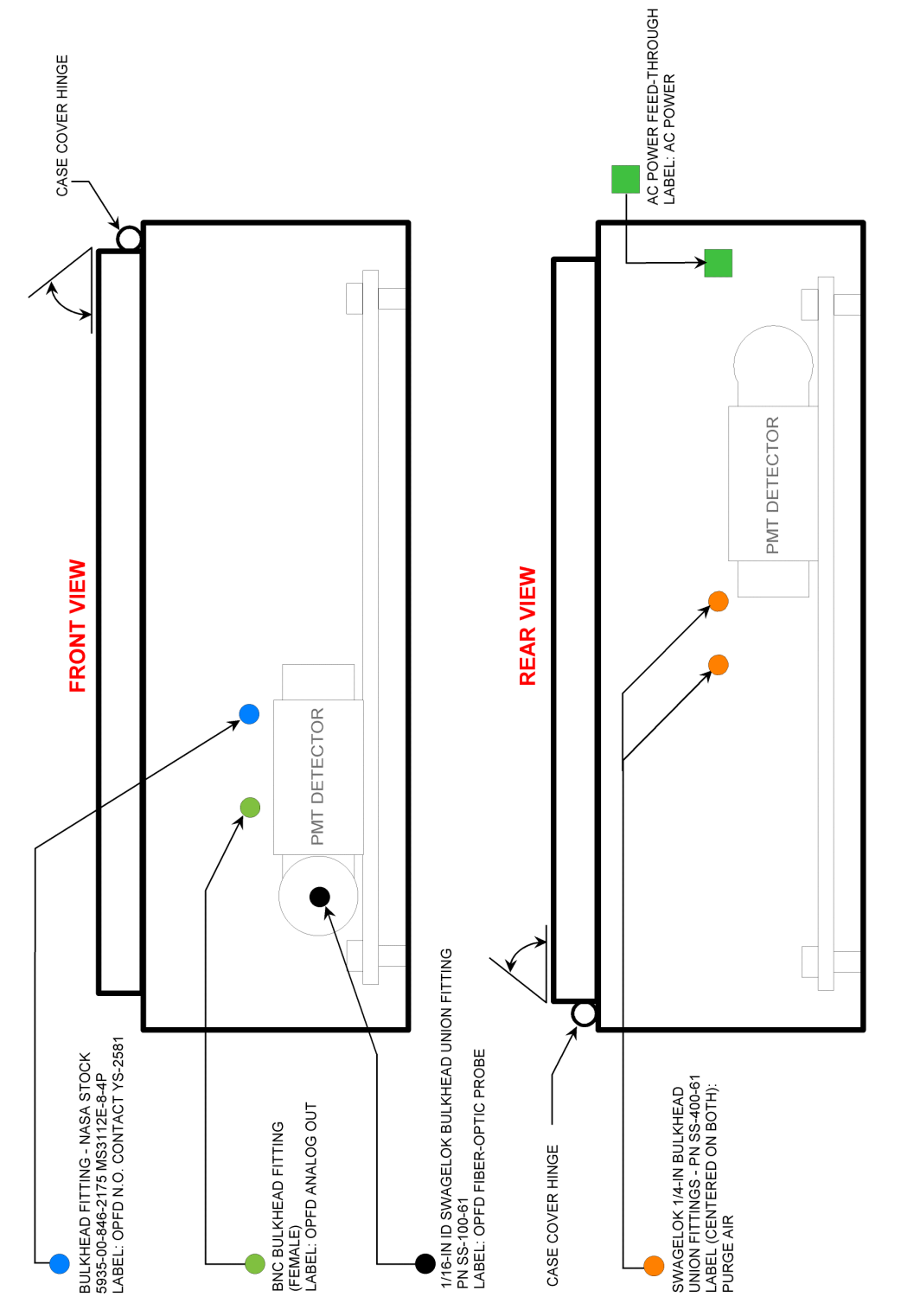
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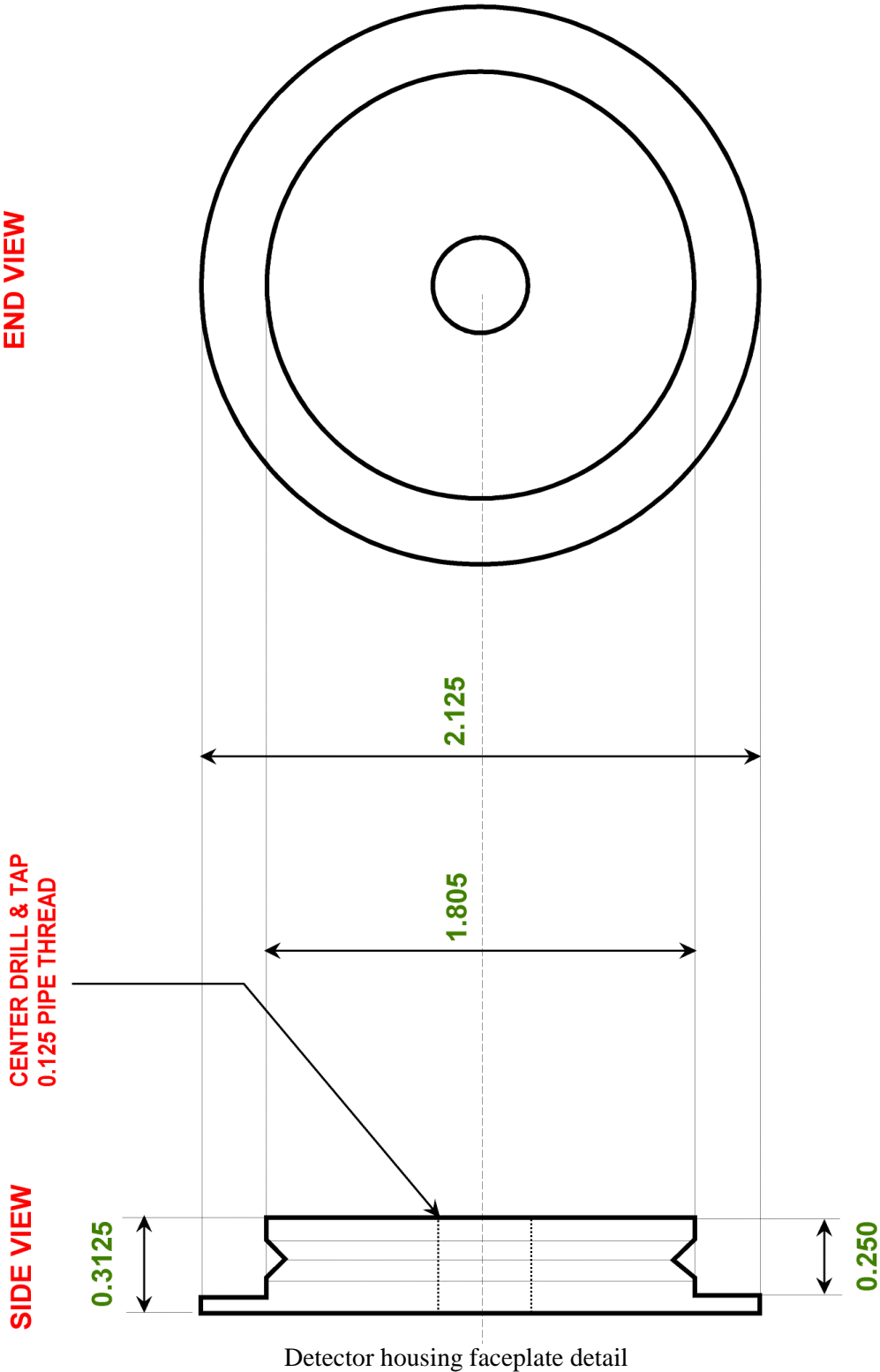
OPFD chassis component sketch

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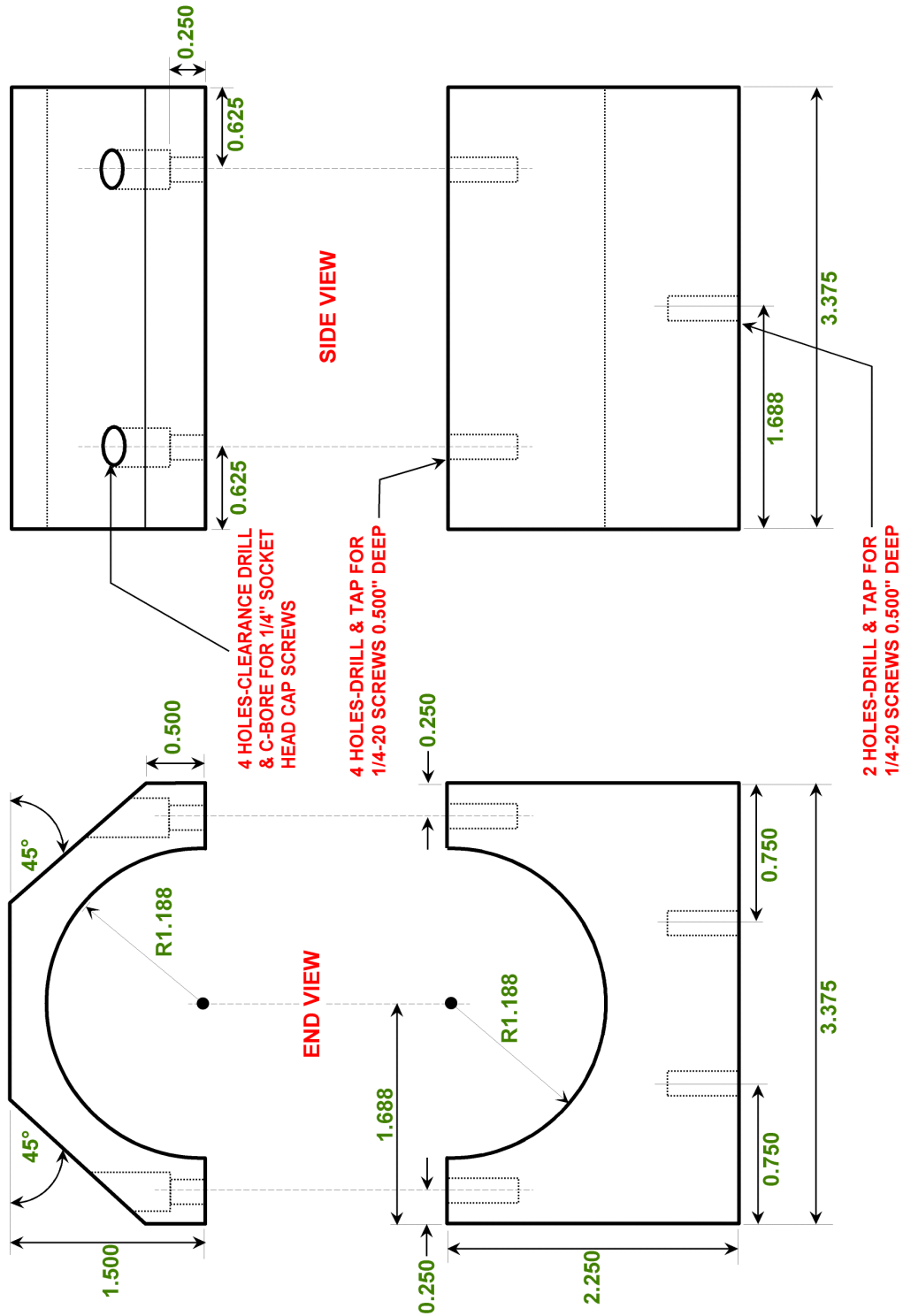


OPFD chassis labeling & external connections

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APPENDIX C **DRAWINGS, SCHEMATICS AND OTHER DOCUMENTATION**



Detector housing support block detail

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